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ORIGINAL ARTICLE

Male Health

Male external genitalia growth curves and charts for children and adolescents aged 0 to 17 years in Chongqing, China

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Genital size is a crucial index for the assessment of male sexual development, as abnormal penile or testicular size may be the earliest visible clinical manifestation of some diseases. However, there is a lack of data regarding penile and testicular size measurements for Chinese boys at all stages of childhood and puberty. This cross-sectional study aimed to develop appropriate growth curves and charts for male external genitalia among children and adolescents aged 0–17 years in Chongqing, China. A total of 2974 boys were enrolled in the present study. Penile length was measured using a rigid ruler, penile diameter was measured using a pachymeter, and testicular volume was determined using a Prader orchidometer. Age-specific percentile curves for penile length, penile diameter, and testicular volume were drawn using the generalized additive models for location, scale, and shape. Very similar growth curves were found for both penile length and penile diameter. Both of them gradually rose to 10 years of age and then sharply increased from 11 to 15 years of age. However, testicular volume changed little before the age of 10 years. This study contributes to the literature covering age-specific growth curve and charts about male external genitalia in Chinese children and adolescents. These age-related values are valuable in evaluating the growth and development status of male external genitalia and could be helpful in diagnosing genital disorders.

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Keywords: adolescents; children; generalized additive model for location, scale, and shape; growth curves; penile size; testicular volume

INTRODUCTION

In males, external genitalia serve important physiologic functions, especially for fertility. Consultations with patients and their parents regarding the size of the penis and testes are very common in pediatric, urologic, endocrinologic, and surgical clinics.¹ Genital size is a crucial index for the assessment of male sexual development: abnormal penile or testicular size may be the earliest visible clinical manifestation of hypogonadotropic hypogonadism, primary hypogonadism, androgen insensitivity, and genetic syndromes, including Klinefelter, Kallmann, Prader–Willi, and Laurence–Moon–Biedl syndromes. For this reason, an early diagnosis of abnormal size in penile or testicular is important for both medical and psychological therapy. Age-specific curves and charts are a simple and rapid approach for early evaluation and diagnosis for abnormal genital size.

The generalized additive model for location, scale, and shape (GAMLSS) provides a growth curve that allows the user to design distribution parameters as a function of an explanatory variable (e.g., age). It has been used by the Multicentre Growth Reference Study (MGRS) of World Health Organization (WHO) group in constructing growth reference curves for school-age children and adolescents.² GAMLSS is also widely used to develop various growth references for such characteristics as lung function,³ birth weight,⁴ grip

strength,⁵ and blood pressure.⁶ However, it has not been used to develop growth curves for assessing male external genitalia. GAMLSS-based growth curves could provide an appropriate assessment tool for smaller penises and testes and allow for the appropriate comparisons among different groups of children or adolescents.

Previous studies have confirmed the existence of ethnic differences regarding the size of the penis and testes.^{7–9} Normal growth curves and tables for the male penis have been reported for several different countries.^{10–18} Nevertheless, most of the previous studies have applied only penile length measurements in newborns or prepubertal boys;^{10–14} there is no study evaluating both penile and testicular size measurements in Chinese boys covering all stages of childhood and puberty.

The purpose of the present study was to develop age-specific percentile growth curves for assessing penile length, penile diameter, and testicular volume in Chinese male children and adolescents aged 0–17 years.

PARTICIPANTS AND METHODS

Subjects

A cross-sectional study was performed between December 2014 and December 2015 at the physical examination center of the Children's Hospital of Chongqing Medical University (Chongqing, China). The

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study subjects were infants and preschool children from outpatient clinics who did not present a disease involving to their genitals. Parental consent was obtained at the time of enrollment in the study. Subjects younger than 7 years old were defined as preschool children; subjects aged 7 years–17 years, 11 months were defined as school-age children and adolescents. Random cluster sampling was used to recruit school-age children and adolescents from the Chongqing area. Three primary schools, three secondary schools, and one high school were selected as the sampling sites. The subjects were stratified by grade, with classes serving as units. All boys belonging to the sample group were initially included, and those who did not wish to participate were excluded. Researchers collected informed consent from all participants or their parents. This study was approved by the Research Ethics Committee of Chongqing Medical University.

Measurements

All measurements were performed in a room at a warm and comfortable temperature. The height was measured without shoes using a digital scale, and their weight was recorded while they were wearing only a T-shirt and underpants. Body mass index (BMI) was calculated from the aforementioned measured weight and height data through the formula weight/height^2 (kg m^{-2}). Genital assessment was conducted by two trained investigators using the same measurement technique, with the subjects in the supine position. The stretched penile length (SPL) during the flaccid state was measured with a rigid centimeter ruler from the pubic ramus to the tip of glans under gentle painless extension of penis using Schonfeld's method.¹⁷ The fatty tissue in the prepubic area was mildly compressed with one end of the ruler down to the pubic ramus. Penile diameter was measured using a pachymeter at the mid-point of the penile shaft. Testicular volume was evaluated with a Prader orchidometer, and the values of the left and right testes were given separately. The mean value was recorded if the interobserver variation was <0.5 cm (for penile length and penile diameter) or 0.5 ml (for testicular volume). Repeated measurements were adopted when variation was greater than or equal to these values.

Statistical analyses

The data were double-entered into a database (EpiData version 3.1 <http://www.epidata.dk/>). Boys aged <1 year were assigned to the 0-year group; boys aged 1 year, 0 day to 2 years were assigned to the 1-year group; boys aged 2 years, 0 day to 3 years were assigned to the 2-year group, and so on. To precisely represent the population of all children and adolescents, the obvious outliers were excluded. Outliers were identified using Tukey's methodology.¹⁹ The interquartile range (IQR) was calculated and outliers were identified as any value greater than 1.5 times IQR below the first quartile or above the third quartile. The Shapiro–Wilk test was used to examine the normality of the data distribution for penile length, penile diameter, and testicular volume. A *t*-test was used to compare the differences between 2 groups, and $P < 0.05$ was considered statistically significant.

We estimated penile length, penile diameter, and testicular volume percentile curves for children and adolescents by age using the GAMLSS model for the Box-Cox Power Exponential (BCPE) or the Box-Cox Cole Green (BCCG) distribution with cubic-spline smoothing.²⁰ The BCPE distribution can be described using four parameters: M for median, S for coefficient of variation, L for Box-Cox transformation power, and T as a parameter related to kurtosis. The Bayesian Information Criterion (BIC) was used to identify the best model, here found to be that with the smallest BIC value. The final best models were based on the BCPE distribution for penile length,

penile diameter, and mean testicular volume. The 3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentile values were calculated by age for penile length, penile diameter, and mean testicular volume separately. All statistical analyses were performed using the GAMLSS (5.0–1) library²¹ running R (version 3.3.3 www.r-project.org) for Windows.

RESULTS

A total of 3033 boys underwent genital size measurement during the study period. An application of Tukey's method resulted in 59 records (1.9% of the observations) being outliers. Thus, a total of 2974 children and adolescents for further analysis were included in the final database.

The Shapiro–Wilk test results showed that SPL followed a normal distribution for the 15-year ($P = 0.1578$) and 17-year age groups ($P = 0.3549$), but not for other age groups ($P < 0.01$). In addition, neither penile diameter nor the volume of the left or right testes followed a normal distribution in any age group (all $P < 0.01$). There was no significant difference in testicular volume between the left and right testes in any age group (all $P > 0.05$).

The mean values and standard deviations (s.d.) for height, weight, BMI, penile length, penile diameter, and left and right testicular volumes for children and adolescents in each age group are shown in **Table 1**. The age-specific smoothed percentile values (e.g. 3rd, 10th, 25th, 50th, 75th, 90th, and 97th) for penile length, penile diameter, and mean testicular volume by age are shown in **Table 2**. The age-specific smoothed percentile curves for male external genitalia by age are shown in **Figure 1** and **2**.

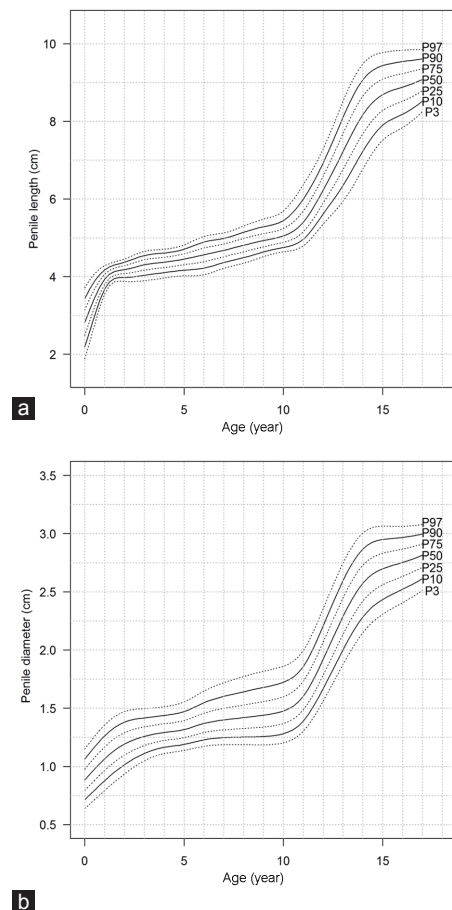


Figure 1: Smoothed percentile curves for (a) penile length and (b) penile diameter by age. P3, P10, P25, P50, P75, P90, and P97 indicate 3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentiles, respectively.

Table 1: Height, weight, body mass index, penile length, penile diameter, and testicular volume for Chinese children and adolescents by each age group (mean±s.d.)

Age (year)	n	Height (cm)	Weight (kg)	BMI (kg m ⁻²)	Penile length (cm)	Penile diameter (cm)	Volume of left testis (ml)	Volume of right testis (ml)
0	98	70.71±7.33	8.20±2.69	17.12±1.86	2.78±0.50	0.88±0.14	1.12±0.33	1.10±0.32
1	173	84.26±5.58	12.55±1.93	16.23±1.79	3.93±0.19	1.07±0.14	1.31±0.38	1.31±0.38
2	249	94.37±5.21	14.77±1.47	16.08±1.95	4.17±0.15	1.20±0.16	1.42±0.45	1.42±0.45
3	124	101.50±4.30	16.75±2.57	16.20±1.64	4.30±0.20	1.26±0.10	1.47±0.50	1.47±0.50
4	89	108.15±4.88	18.92±3.17	16.10±1.72	4.36±0.20	1.30±0.11	1.52±0.50	1.52±0.50
5	81	112.08±7.81	20.12±3.17	16.07±2.27	4.45±0.20	1.31±0.11	1.61±0.46	1.60±0.45
6	162	117.87±6.62	22.87±3.66	16.43±1.95	4.55±0.27	1.39±0.13	1.85±0.51	1.85±0.51
7	185	123.94±6.18	24.72±4.43	15.99±1.72	4.67±0.23	1.41±0.15	2.03±0.39	2.04±0.41
8	215	127.24±9.66	27.45±5.33	16.60±2.10	4.81±0.26	1.44±0.15	2.30±0.47	2.30±0.47
9	157	132.86±6.52	29.64±5.18	16.70±1.93	4.94±0.26	1.44±0.16	2.63±0.68	2.63±0.68
10	226	138.10±7.03	33.29±6.43	17.30±2.30	5.08±0.29	1.51±0.19	3.48±1.37	3.48±1.37
11	217	143.30±10.40	36.93±8.45	18.56±3.10	5.44±0.44	1.59±0.17	4.86±1.98	4.87±1.99
12	194	149.72±9.56	41.50±10.30	18.33±3.35	6.28±0.49	1.96±0.22	7.61±3.12	7.60±3.13
13	201	157.18±8.35	48.42±10.71	19.40±3.13	7.17±0.70	2.27±0.23	10.68±4.28	10.68±4.26
14	203	161.70±7.90	51.74±10.90	19.64±3.25	8.20±0.72	2.60±0.23	13.20±4.65	13.08±4.51
15	190	166.58±6.51	57.90±11.00	20.75±3.14	8.63±0.56	2.69±0.19	15.48±4.71	15.44±4.71
16	157	167.33±6.56	57.95±10.30	20.61±2.99	8.87±0.54	2.75±0.18	17.94±3.57	17.75±3.47
17	53	170.21±5.75	63.48±9.74	21.89±3.08	9.07±0.43	2.81±0.15	16.32±2.46	16.32±2.46

BMI: body mass index; s.d.: standard deviation

Table 2: Smoothed percentiles for penile length, penile diameter and testicular volume in males aged 0–17 years of China

Age (year)	n ^a	Penile length (cm)							Penile diameter (cm)							Mean testicular volume (ml)						
		P3	P10	P25	P50	P75	P90	P97	P3	P10	P25	P50	P75	P90	P97	P3	P10	P25	P50	P75	P90	P97
0	98	1.88	2.18	2.48	2.81	3.14	3.43	3.71	0.64	0.71	0.79	0.88	0.98	1.06	1.15	0.55	0.63	0.81	1.15	1.54	1.80	1.93
1	173	3.55	3.68	3.80	3.93	4.06	4.17	4.28	0.79	0.88	0.97	1.07	1.17	1.26	1.36	0.84	0.91	1.06	1.34	1.68	1.91	2.04
2	249	3.88	3.98	4.07	4.18	4.28	4.37	4.45	0.93	1.01	1.10	1.20	1.29	1.38	1.47	0.92	0.98	1.12	1.38	1.70	1.93	2.06
3	124	3.89	4.03	4.16	4.30	4.43	4.54	4.65	1.05	1.11	1.18	1.26	1.34	1.42	1.50	0.95	1.01	1.14	1.40	1.72	1.96	2.11
4	89	3.96	4.10	4.23	4.37	4.50	4.60	4.70	1.11	1.17	1.22	1.30	1.37	1.44	1.51	0.95	1.02	1.14	1.40	1.72	1.98	2.14
5	81	4.02	4.17	4.30	4.45	4.59	4.70	4.81	1.14	1.19	1.25	1.32	1.40	1.47	1.55	0.95	1.02	1.14	1.40	1.74	2.02	2.23
6	162	4.04	4.21	4.38	4.56	4.74	4.89	5.04	1.17	1.23	1.29	1.37	1.46	1.55	1.65	0.99	1.05	1.18	1.45	1.83	2.17	2.42
7	185	4.21	4.36	4.51	4.68	4.84	4.98	5.12	1.19	1.25	1.31	1.40	1.50	1.60	1.72	1.19	1.28	1.44	1.77	2.26	2.69	3.04
8	215	4.34	4.49	4.64	4.81	4.98	5.14	5.30	1.19	1.25	1.33	1.42	1.53	1.64	1.77	1.21	1.31	1.49	1.88	2.44	2.95	3.40
9	157	4.51	4.63	4.77	4.93	5.11	5.29	5.48	1.19	1.26	1.34	1.44	1.56	1.68	1.82	1.30	1.43	1.66	2.15	2.92	3.69	4.42
10	226	4.64	4.75	4.88	5.05	5.24	5.44	5.69	1.20	1.28	1.37	1.48	1.60	1.72	1.86	1.43	1.61	1.93	2.60	3.68	4.80	5.95
11	217	4.79	4.96	5.15	5.40	5.69	6.00	6.37	1.30	1.39	1.49	1.60	1.73	1.86	1.99	2.19	2.59	3.22	4.48	6.26	7.92	9.48
12	194	5.35	5.62	5.90	6.23	6.59	6.92	7.28	1.56	1.67	1.78	1.92	2.07	2.21	2.36	3.41	4.27	5.56	7.79	10.55	12.89	14.96
13	201	5.93	6.34	6.76	7.22	7.69	8.11	8.52	1.88	2.00	2.13	2.29	2.45	2.60	2.75	4.49	5.84	7.71	10.67	14.12	17.01	19.61
14	203	6.76	7.22	7.68	8.17	8.64	9.06	9.46	2.15	2.28	2.42	2.57	2.73	2.87	3.01	6.27	7.73	9.68	12.66	16.19	19.35	22.38
15	190	7.53	7.91	8.27	8.66	9.03	9.36	9.66	2.31	2.44	2.56	2.70	2.83	2.95	3.06	8.68	9.94	11.58	14.06	17.18	20.33	23.77
16	157	7.83	8.18	8.52	8.88	9.23	9.53	9.82	2.41	2.52	2.63	2.75	2.87	2.97	3.06	10.94	11.96	13.26	15.17	17.70	20.64	24.46
17	53	8.25	8.52	8.79	9.08	9.36	9.62	9.86	2.51	2.61	2.71	2.81	2.91	3.00	3.08	12.90	13.74	14.76	16.20	18.14	20.66	24.54

^aThe number of boys in each age group. P3–P97: predicted smoothed percentiles from generalized additive model for location, scale, and shape

The growth of penile length increased rapidly in the 1st year of life, and then gradually began to increase until 10 years of age. A marked increase was observed between 11 and 15 years of age. After this, penile growth was relatively slow and changed little (**Figure 1a**). The growth of penile diameter was similar to that of penile length, showing pronounced growth between 0 and 3 years of age, and again after age 11 (**Figure 1b**). Testicular volume showed almost no change before the age of 10 years; there was only a 1–2 ml increase during the first 10 years of life. However, testicular size increased sharply from 11 to 16 years of age, after which, the slope of the curve progressively declined, indicating a much slower increase in testicular volume (**Figure 2**).

DISCUSSION

Studies that list the growth curves of penile size are not uncommon; however, the normal range for these studies has been described in terms of mean ± s.d.^{11,13,16} Those studies do not usually smooth the standard curves using appropriate distribution, such as a log normal or Box-Cox Power Exponential distribution with a cubic-smoothing spline function. The lack of smoothing may lead to very irregular growth curves, even with large sample sizes. In addition, various investigators have reported ethnic differences for penile size and testicular volume.^{7,8,22} According to Fok *et al.*,⁸ full-term Chinese infants have shorter penises than other Asian counterparts and Caucasians, which means that Chinese children may be diagnosed

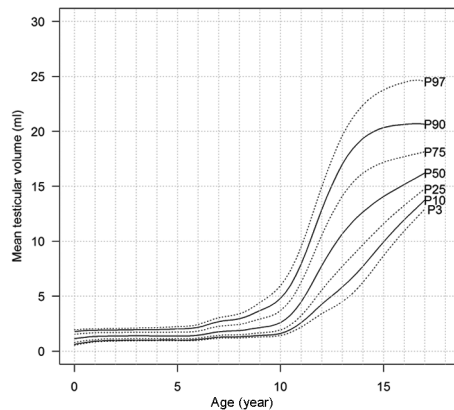


Figure 2: Smoothed percentile curves for mean testicular volume by age, P3, P10, P25, P50, P75, P90, and P97 indicate 3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentiles, respectively.

with micropenis if no appropriate local reference values are available. Using the GAMLSS method, our study provided an age-specific growth curve and chart for penile length, penile diameter, and testicular volume for Chinese boys between the ages of 0 and 17 years, which has not been previously used to evaluate the development of male external genitalia.

Abnormal size of the penis and testes could be the earliest visible clinical manifestation of deficiencies in the function of hypothalamic-pituitary-gonadal (HPG) axis and the secretion of related hormones, so precise measurement of penis and testes is a precondition of assessment. Since its initial use by Schonfeld and Beebe,¹⁷ SPL has been considered the gold standard for measurement of penile length, and it has been utilized in various studies.^{8–16} Smith *et al.*²³ successfully used ultrasonography for penile measurement and found there to be a significant difference between ultrasonography and conventional methods of penile measurement. However, further studies are still needed to assess the limitation of the ultrasonography in the measurement of larger penises. Ultrasonography is also used for measurement of testicular volume. Goede *et al.*²⁴ assessed the validity of the Prader orchidometer per age group by comparing its finding to volume measurements made by ultrasonography, and a close correlation was found between these two modalities ($R^2 = 0.956$). These results revealed that volume as measured using the Prader orchidometer can serve as a valid method for monitoring testicular growth. Given the inconvenience and high cost of ultrasonography for large groups of subjects, classical measurements for testicular size such as those involving the orchidometer are a practical option. Furthermore, a strict quality control by the experienced doctors provided a guarantee in the accuracy of the measurements.

There is no general agreement as to the pattern of penile growth. A previous study by Schonfeld and Beebe¹⁷ reported that the penis grows slowly to the age of 5 years, followed by a relatively steady phase. Growth then increases rapidly during puberty. This pattern of penile growth was also demonstrated in a study of penile size performed in Brazil.¹⁵ However, in our study, we found that penile length increased continuously after birth, showing peak growth from 11 to 15 years of age. This is similar to findings reported in other studies in Korea¹⁶ and Bulgaria.¹⁸

In the present study, we also found a greater growth rate for penile length in the first year after birth. Similarly, Boas *et al.*²⁵ reported

that a rapid increase in penile growth took place during the first 3 months after birth, coinciding with an infant's high concentrations of testosterone. The report made by Camurdan *et al.*¹¹ indicated that the quickest increase in penile length took place during in the first 6 months after birth. In a Japanese study, penile size increased continuously throughout the pre-pubertal period, and most rapidly during the first 4 months of life.¹⁴ It is known that the development of the penis depends on the levels of testosterone in the body, and in healthy males, the HPG axis is transiently activated during the first month of postnatal life. The gonadal hormones and gonadotropins increase to a pubertal or even adult levels (so-called "mini-puberty"), followed by a relatively quiescent period until reactivation of the HPG in puberty.^{26,27}

When comparing the growth curves for the penis and testes, we can readily observe that testicular enlargement precedes rapid lengthening of the penis. The increase in the testes in our study took place up to 1 year earlier than the increase in penile size. This developmental pattern for male external genitalia is consistent with developmental sequences.¹⁸ According to Tanner *et al.*,²⁸ the criterion for the onset of puberty is testicular volume, not penile length. Testicular volumes of 4 and 12 ml represent the first clear sign of the pubertal increase, and the attainment of mid- or late puberty, respectively. The boys whose testicular volume reached an average of 4 ml in our study were about 10 to 11 years of age, and the testes reached an average of 12 ml at an age of 13–14 years. This finding was similar to a survey from the Chinese Medical Association, which found that the median age at onset of puberty for urban Chinese boys as indicated by a testicular volume of 4 ml or more was 10.55 (95% CI 10.27–10.79) years, and for 12 ml or more was 13.42 (95% CI 13.04–13.79) years.²⁹

From our results, we were able to demonstrate the wide differences between the 3rd and 97th percentiles. For example, the penis of 14-year-old boy had a mean (s.d.) length of 8.20 (0.72) cm (3rd–97th percentile: 6.76–9.06 cm); the testes had a mean (s.d.) volume of 13.14 (4.58) ml (3rd–97th percentile: 6.27–23.38 ml). These findings are most likely due to the fact that, during adolescence, people of the same age can be at different stages of sexual development. In a recent article by Soydan *et al.*,³⁰ males aged 13–15 years were evaluated, and profound variability in penile length was detected within the same age group. These authors stated that penile length during puberty should be evaluated individually according to the child's current pubertal stage. For this reason, we suggest that the large variations be taken into consideration when evaluating growth and development in normal boys of the same age, especially during puberty.

Our study has several strengths. First, this was a large cross-sectional population-based study of the growth of male external genitalia in China and it covered all stages of childhood and puberty. Second, we used an advanced statistical method to establish predictive percentiles for penile length, penile diameter, and testicular volume. Third, the age-specific percentile values provided by this study were highly suitable for use in clinical practice. However, several limitations should be noted. First, only urban boys were included in our study, which may not adequately represent the population of other areas in China. Second, the study was cross-sectional design. Clearly, there is a need to substantiate these findings in a longitudinal study. Third, testicular volume was measured using conventional Prader orchidometer. However, the Prader orchidometer might overestimate the testicular volume in small testes.³¹ Fourth, we did not here take into account the potential impact of recognized determinants of male external genitalia, such as height, weight, or BMI, on the percentile values presented. The paucity of information in this area requires further research.

CONCLUSIONS

To the best of our knowledge, we have developed the first age-specific smoothed percentile curves for penile length, penile diameter, and testicular volume for Chinese boys aged 0 to 17 years using the popular GAMLSS method. These age-specific percentile values may be helpful in informing the clinical assessments of penile size and testicular size to assist with the prompt diagnosis of genital abnormalities.

AUTHOR CONTRIBUTIONS

YNW was responsible for literature consulting, data analysis, and manuscript writing. YZ conceived and designed this study and engaged in data collection and entry. QZ contributed to statistical analysis and completion of final manuscript. FX participated in the study design and supervision. All authors read and approved the final manuscript.

COMPETING INTERESTS

All authors declared no competing interests.

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